Global J. of Engng. Educ., Vol.10, No.2
Published in Australia

A Sustainable, Systematic Process for Continuous Programme Improvement*

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The USA Accreditation Board for Engineering and Technology (ABET) adopted recently a new set of criteria for evaluating engineering programmes. One of these (criterion 3) refers to programme outcomes and assessment. In this article, the author describes the design and implementation of a sustainable, systematic process for defining and assessing programme outcomes. This process involves analysing each outcome into elements, defining a set of attributes for each element, selecting outcome indicators and performance targets, and developing special rubrics for an accurate assessment of student skills. The author also describes a systematic way of addressing specific programme outcomes through course and curriculum design. Each outcome is assessed in a group of selected courses in an effort coordinated by several faculty members. Course changes are implemented as necessary to increase students' achievements in critical areas. The focus of this effort is to create a process that facilitates the continuous improvement of a programme.

INTRODUCTION

The USA Accreditation Board for Engineering and Technology (ABET) recently adopted a new set of criteria for evaluating engineering programmes. One of these, criterion 3, refers to Programme Outcomes (POs) [1]. POs *describe what students are expected to know or be able to do by the time of graduation from the programme*.

A systematic process must be in place to assess the achievement of all the POs before students graduate. This process needs to be ongoing to ensure the continuous improvement of each programme.

In this article, the author describes the design and implementation of such a systematic process in the Aerospace Engineering (AE) and Mechanical Engineering (ME) programmes at San José State University (SJSU) in San José, USA.

*A revised and expanded version of a paper presented at the *9th UICEE Annual Conference on Engineering Education*, held in Muscat, Oman, from 11 to 15 January 2006. This paper was awarded the UICEE bronze award (joint fifth grade with two other papers) by popular vote of Conference participants for the most significant contribution to the field of engineering education.

PROGRAMME OUTCOMES

ABET Criterion 3 requires engineering programmes seeking accreditation to demonstrate that their graduates have the following:

a. An ability to apply knowledge of mathematics, science and engineering;
b. An ability to design and conduct experiments, as well as to analyse and interpret data;
c. An ability to design a system, component or process to meet desired needs within realistic constraints, such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability;
d. An ability to function on multidisciplinary teams;
e. An ability to identify, formulate and solve engineering problems;
f. An understanding of professional and ethical responsibility;
g. An ability to communicate effectively;
h. The broad education necessary to understand the impact of engineering solutions in a global and societal context;
i. A recognition of the need for, and an ability to, engage in life-long learning;

j. A knowledge of contemporary issues;
k. An ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

Engineering schools are encouraged to expand/reword each outcome, combine outcomes and write additional ones, as needed, to reflect specific strengths of their programmes. For example, outcomes 3a and 3i for an aerospace engineering programme could be combined and expanded to read as follows:

> *... an ability to apply knowledge of mathematics, science, and engineering to identify, formulate and solve aerospace engineering problems in aerodynamics, aerothermodynamics, structures, propulsion, flight mechanics, stability and control, using analytical and numerical methods.*

OUTCOME ELEMENTS AND ATTRIBUTES

Because the outcomes are rather comprehensive and difficult to assess as stated, Felder and Brent suggest that each outcome be analysed into elements – different abilities specified in the outcome – and that a set of attributes be defined for each element – actions that explicitly demonstrate mastery of the abilities specified [2]. This analysis is detailed below.

Outcome 3a: Elements and Attributes

(a1) Ability to apply knowledge of mathematics:

- Apply mathematics to solve AE/ME problems;
- Apply calculus (differentiation, integration, etc) to solve AE/ME problems;
- Apply differential equations to solve AE/ME problems;
- Apply linear algebra (matrices, systems of equations) to solve AE/ME problems;
- Apply statistics to solve AE/ME problems.

(a2) Ability to apply knowledge of science:

- Apply chemistry principles (eg chemical balance equations) to solve AE/ME problems;
- Apply equilibrium principles and Newton's laws (including free-body diagrams) to solve AE/ME problems;
- Apply physics concepts (friction, thermal/fluid concepts etc) to solve AE/ME problems.

(a3) Ability to apply knowledge of engineering:

- Apply engineering principles (eg fluid mechanics, dynamics, heat transfer, etc) to solve AE/ME problems.

Outcome 3b: Elements and Attributes

(b1) Ability to design an experiment:

- Discuss the importance and practical applications of the experiment;
- Given the goal(s) of an experiment, define specific objectives;
- Research and summarise relevant theory and published data from similar experiments;
- Select the dependent and independent variable(s) to be measured and the proper range for each variable;
- Select the appropriate methods for measuring the selected variables;
- Determine an appropriate number of data points needed for each type of measurement;
- Choose appropriate equipment and instrumentation;
- Sketch the experimental set-up and describe a step-by-step procedure for performing the experiment.

(b2) Ability to conduct an experiment:

- Become familiar with the equipment in a laboratory;
- Calibrate the instruments to be used;
- Follow the proper procedures to collect data.

(b3) Ability to analyse a set of experimental data:

- Carry out the necessary calculations;
- Perform an error analysis of experimental data;
- Tabulate and plot experimental results using an appropriate choice of variables and software.

(b4) Ability to interpret experimental data:

- Make observations and draw conclusions regarding the variation of the parameters involved;
- Compare experimental results with predictions from theory, computer simulations or other published data and explain any discrepancies.

Outcome 3c: Elements and Attributes

The attributes described below are applicable to all three elements of outcome 3c. In other words, students need to possess these skills regardless of whether they design a component, a system or a process to meet desired needs:

- Develop a flowchart of the design process;
- Investigate and evaluate prior/related solutions for the need they are trying to address;
- Develop constraints and criteria for evaluation;
- Develop and analyse alternative solutions;
- Perform trade studies using appropriate parameters;
- Choose the best solution considering the criteria for evaluation;
- Develop final performance specifications;
- Communicate the results of their design orally, as well as in writing (sell their design);
- Build a prototype and demonstrate that it meets the performance specifications;
- List and discuss several possible reasons for deviations between predicted and measured design performance;
- Choose the most likely reason for a deviation between predicted and measured design performance and justify the choice.

Outcome 3d: Elements and Attributes

(d1) Ability to work effectively in a team:

- Set goals related to a team project;
- Organise and delegate work among team members;
- Generate and follow a timeline for the completion of a project;
- Understand the team's direction and communicate clearly with team members;
- Participate in decision making;
- Negotiate with partners;
- Resolve conflicts arising during teamwork;
- Take initiative and responsibility for various tasks;
- Motivate, coach and discipline team members, as needed, to ensure that all tasks are completed;
- Exhibit a positive attitude, encourage others and seek consensus.

(d2) Ability to work effectively in a multidisciplinary environment:

- Understand the basics from other fields (eg different branches of engineering/physical sciences, economics, management, etc) to communicate effectively with team members from these fields;
- Communicate ideas relating to AE/ME in terms that others outside their discipline can understand.

Outcome 3e: Elements and Attributes

The following attributes were adapted from Woods et al [3]. It is interesting to note that these attributes come from both the affective and the cognitive domains in Bloom's taxonomy of educational objectives, as indicated below [4][5]. This observation suggests that students need to develop first certain attitudes before they acquire the skills necessary to tackle open-ended, engineering problems:

- Are willing to spend time reading, gathering information and defining the problem [affective – level 2];
- Use a process, as well as a variety of tactics and heuristics, in order to tackle problems [cognitive – level 4];
- Monitor their problem-solving process and reflect upon its effectiveness [cognitive – level 4];
- Emphasise accuracy rather than speed [affective – level 3];
- Write down ideas and create charts/figures, while solving a problem [cognitive – level 3];
- Are organised and systematic [affective – level 4];
- Are flexible (keep options open, can view a situation from different perspectives/points of view) [affective – level 4];
- Draw on the pertinent subject knowledge, and objectively and critically assess the quality, accuracy and pertinence of that knowledge/data [cognitive – level 3];
- Are willing to risk and cope with ambiguity, welcoming change and managing stress [affective – level 4].
- Use an overall approach that emphasises fundamentals, rather than trying to combine various memorised sample solutions [cognitive – level 4].

Outcome 3f: Elements and Attributes

(f1) Understanding of professional responsibility:

- Demonstrate knowledge of a professional code of ethics;
- Demonstrate an understanding of the impact of the profession on society and the environment;
- Demonstrate professional excellence in performance, punctuality, collegiality and service to the profession.

(f2) Understanding of ethical responsibility:

- Given a job-related scenario that requires a decision with ethical implications, identify possible courses of action and discuss the pros and cons of each one;
- Given a job-related scenario that requires a decision with ethical implications, decide on the best course of action and justify the decision.

Outcome 3g: Elements and Attributes

(g1) Effective in written communication:

- Produce well-organised reports following guidelines;
- Use clear and correct language and terminology while describing experiments, projects or solutions to engineering problems;
- Describe accurately in a few paragraphs a project/experiment performed, the procedure used, and the most important results (abstracts, summaries).

(g2) Effective in oral communication:

- Communicate clearly and effectively in small group settings;
- Give well-organised presentations following guidelines;
- Use visuals to convey a message effectively when making presentations;
- Present the most important information about a project/experiment while staying within their allotted time when making presentations.

Outcome 3h: Elements and Attributes

- Describe accurately and evaluate the environmental impact of various engineering products, including those designed in course projects;
- Describe accurately and evaluate the environmental and economic tradeoffs of engineering products, including those designed in course projects;
- Describe accurately and evaluate the health/safety impact of engineering products, including those designed in course projects;
- Take into consideration the environmental impact when designing an engineering product;
- Take into consideration the health/safety impact when designing an engineering product.

Outcome 3i: Elements and Attributes

(i1) Recognition of the need for life-long learning:

- Willing to learn new content through individual research and study;
- Read engineering articles/books outside of class;
- Reflect on one's learning process;
- Participate in professional societies;
- Attend extracurricular training;
- Plan to attend graduate school.

(i2) Ability to engage in life-long learning:

- Observe engineering artefacts carefully and critically to reach an understanding of the reasons behind their design;
- Access information effectively and efficiently from a variety of sources;
- Read critically and assess the quality of information available (eg question the validity of information, including that from textbooks or teachers);
- Categorise and classify information;
- Analyse new content by breaking it down, asking key questions, comparing and contrasting, recognising patterns, and interpreting information;
- Synthesise new concepts by making connections, transferring prior knowledge and generalising;
- Model by estimating, simplifying, and making assumptions and approximations;
- Visualise (eg create pictures in their mind that help them see what the words in a book describe);
- Reason by predicting, inferring, using inductions, questioning assumptions, using lateral thinking and inquiring.

Outcome 3j: Elements and Attributes

A working definition of *contemporary* is *having particular relevance to the present time*. Some examples of current contemporary issues are international conflict, terrorism, pollution, natural resources and energy conservation, urban development (traffic, housing), bioethics, market and workforce globalisation, mobile technology and communications, information management and information security.

- List several examples of contemporary issues related to engineering and technology, and articulate a problem statement or position statement for each;
- Explain what makes these issues particularly relevant to the present time;
- Suggest reasonable theories regarding the root causes of contemporary problems;
- Identify possible solutions to contemporary problems, as well as any limitations of these solutions.

Outcome 3k: Elements and Attributes

- Use state-of-the-art technology for engineering system design, control and analysis;
- Be skilled in Web-based research;
- Use state-of-the-art software to write technical reports and give oral presentations;
- Use computer simulations to conduct parametric studies, process optimisation and *what if* explorations;
- Use modern equipment and instrumentation in engineering laboratories;
- Be aware of state-of-the-art tools and practices used in industry through plant visits and presentations by practicing engineers.

To ensure that students acquire higher-order skills in each outcome, attributes were defined for each of the six levels of Bloom's taxonomy in the cognitive domain and for each of the five levels in the affective domain [4][5]. Ref. [6] provides excellent guidelines for defining outcome attributes.

OUTCOME INDICATORS AND PERFORMANCE TARGETS

Two outcome indicators were utilised in order to assess students' attainment of the programme outcomes, namely:

- Course performance ratings based on graded student work;
- Student surveys.

To satisfy Criterion 3, performance targets were defined as follows:

- The scores earned by all students in the assignments and test questions, which pertain to a particular outcome, in each course where this outcome is measured, must be at least 60% (this corresponds to a grade of C-, the lowest passing grade in core courses);
- The ratings pertaining to this outcome, given by at least 70% of the students in each class surveyed, must be I agree on a 3-point Likert scale.

If these targets are met in the courses chosen for the assessment of an outcome, then the outcome is achieved and no further action is needed in this course.

RUBRICS

For accurate assessment, the development and use of special rubrics for each outcome is necessary. This is especially critical for outcomes that involve soft skills, such as teamwork. An example of such a rubric is shown in Table 1 for outcome (3d). In addition to assigning scores for their teammates, each team member is asked to write one or more paragraphs about the work of each member of the team, including

Table 1: Rubric for assessing team skills.

Criteria	Member 2	Member 3	Self
Quality of Technical Work: Work is correct, clear, complete and relevant to the problem. Equations, graphs and notes are clear and intelligible.			
Commitment to Team/Project: Attends all meetings. Arrives on time or early. Prepared. Ready to work. Dependable, faithful and reliable.			
Leadership: Takes initiative, makes suggestions and provides focus. Creative. Brings energy and excitement to the team. Has a *can do* attitude. Sparks creativity in others.			
Responsibility: Gladly accepts work and gets it done. Spirit of excellence.			
Has *abilities* that the team needs. Makes the most of these abilities. Gives fully, does not hold back.			
Communication: Communicates clearly when he/she speaks and when he/she writes. Understands the team's direction.			
Personality: Positive attitudes, encourages others. Seeks consensus. Fun to deal with. Brings out best in others. Peacemaker. Pours water, not gasoline, on fires.			
Average grade			
Grading scale: 5 – Always 4 – Most of the time 3 – Sometimes 2 – Rarely 1 – Never NB: If you award high scores to everyone, regardless of their contribution, team members who have worked unduly hard or provided extraordinary leadership will go unrecognised, as will those at the other end of the scale who need your corrective feedback.			

themselves. These narratives are meant to amplify the ratings given by the following:

- Identifying the strengths and weaknesses of each individual;
- Suggesting ways in which his/her work can be improved. Team members evaluate also the effectiveness of the team as a whole.

OUTCOMES ASSESSMENT

Figure 1 shows the process for assessing outcomes. Each course contributes to at least one outcome. Hence, a particular outcome is addressed in several courses. Nevertheless, a subset of these courses is selected for assessment purposes, using the following requirements:

- Each outcome should be assessed in several courses to ensure that students acquire an appropriate level of breadth and depth in the skills of this outcome;
- The number of courses assessed for each outcome should be kept low to minimise faculty workload;
- The ABET requires that all graduates have the skills described in all 11 outcomes. As a result, elective courses alone cannot be used to make a case that a programme meets a particular outcome.

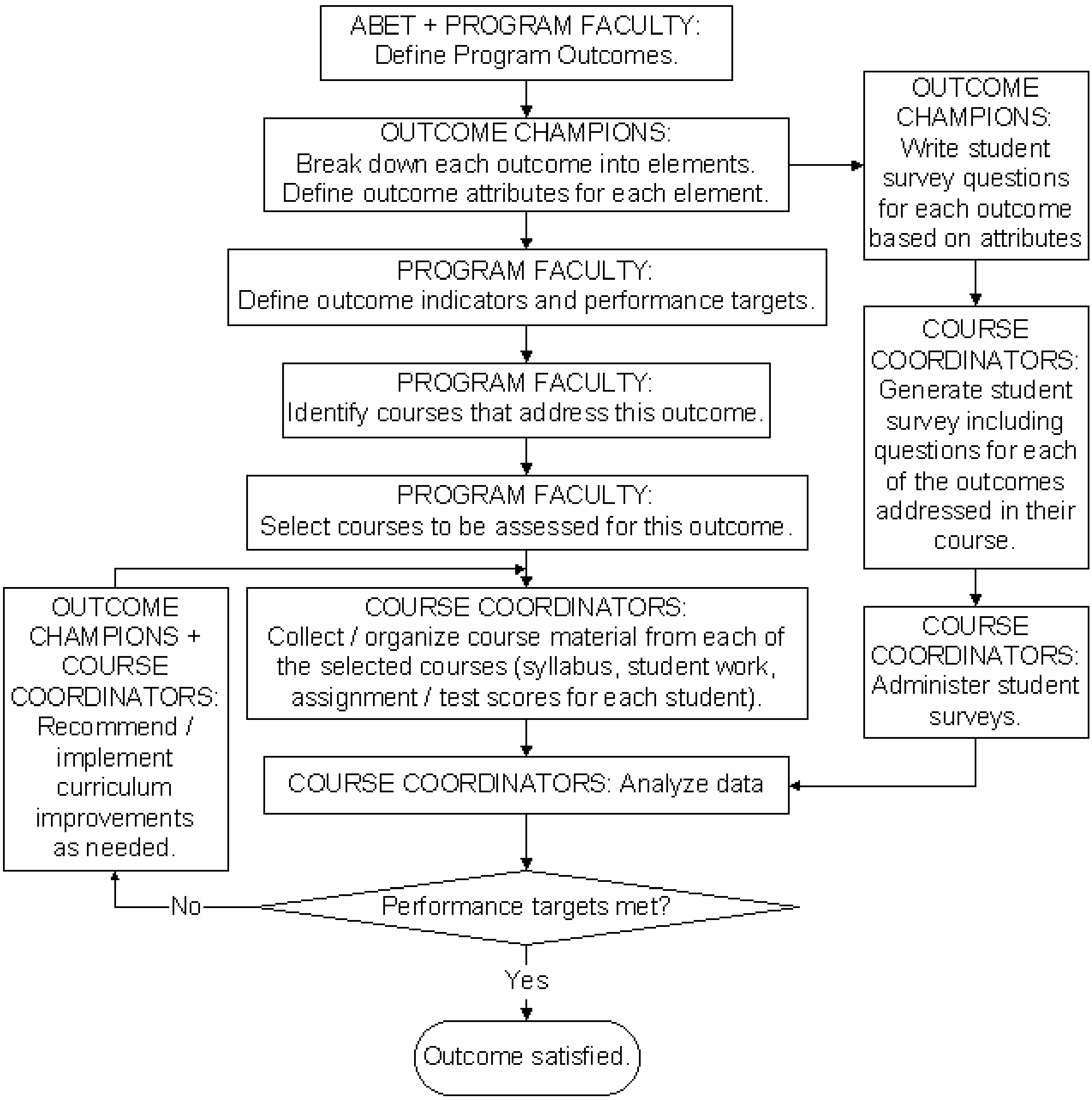

Figure 1: Outcome assessment flowchart.

A large number of engineering students transfer to the SJSU from community colleges in their junior year. Since the University does not receive assessment data from these colleges, freshman and sophomore courses are excluded for programme assessment purposes.

Tables 2 and 3 show the courses selected for each of the two programmes and the outcomes addressed in each course. Information on the content of each course can be found in [7]. Three of the courses assessed (ME111, ME113 and ME120) are common for both programmes.

For each of the courses listed in Tables 2 and 3, the course coordinator must show evidence that the course includes the necessary elements to satisfy a particular outcome and collect/analyse data to show that performance targets are met. Moreover, for each outcome, there is a designated outcome champion. These champions validate the evidence presented by course coordinators for individual courses and have the final word on whether the performance of a programme is satisfactory with regards to their outcome. They meet with course coordinators and instructors, discuss their findings and make recommendations for course improvements. Outcome champions provide an additional level of accountability and ensure consistency in the process.

Outcomes are assessed on a three-year cycle, as shown in Table 4. Each semester, two outcomes are assessed. Thus, it takes five and a half years to complete the assessment of all 11 outcomes and this corresponds to the frequency of the accreditation visits, which occur every six years. Examples of outcomes assessment can be found in ref. [7].

COURSE DESIGN

Students acquire the skills described in the POs mostly through the curriculum of each programme. Hence, the curriculum and course design play a critical role in ensuring that students are indeed prepared in these skills at the time they graduate.

Course Learning Objectives

Course design begins with the definition of specific, detailed and measurable learning objectives. A course

Table 2: AE programme – outcome matrix.

	Outcomes										
	3a	3b	3c	3d	3e	3f	3g	3h	3i	3j	3k
ME111	B			B	C		✓	B	C	B	
ME113	B			B	B		B	B	B	B	
ME120	✓	C		C			C				C
AE162	B	C	B	C	C		C	B	C	B	C
AE164	B	C		C	B		C	B	B	B	C
AE167	B				B			B	B	B	
AE170A, B	✓		C	C	✓	C	C		C		C

Table 3: ME programme – outcome matrix.

	Outcomes										
	3a	3b	3c	3d	3e	3f	3g	3h	3i	3j	3k
ME101	B				B						
ME106	B	B		✓			B				B
ME111	B			B	C		✓	B	C	B	
ME113	B			B	B		B	B	B	B	
ME114	C	C			B		B		B	A	
ME120	✓	C		C			C				C
ME154	✓		C	✓			✓		✓		
ME195A, B	✓		C	C	✓	C	C	B	C		C

Note: B represents levels 3 and 4 in Bloom's Taxonomy.
C represents levels 5 and 6 in Bloom's Taxonomy.
✓ shows that the outcome is addressed but not assessed in this course.

Table 4: The timetable for outcomes assessment.

	Outcomes										
	3a	3b	3c	3d	3e	3f	3g	3h	3i	3j	3k
Fall 2005	X					X					
Spring 2006		X					X				
Fall 2006			X					X			
Spring 2007				X					X		
Fall 2007					X					X	
Spring 2008						X					X
Fall 2008	X						X				
Spring 2009		X						X			
Fall 2009			X						X		
Spring 2010				X						X	
Fall 2010					X						X
Spring 2011	Finalise self-study reports										
Fall 2011	ABET visit										

learning objective (CLO) is an intent, communicated by a statement, describing what students should be able to do with a particular topic in the course. Mager, Gronlund and Stice provide excellent suggestions on how to write CLOs [8-10].

Obviously, CLOs must represent a subset of the skills described in the POs. Table 5 presents a few examples of CLOs from an aerodynamics course and shows how they contribute to POs. Why are CLOs so important in course design? First, they allow instructors to critically evaluate the relative importance of topics and the allocation of instructional time per topic so that they can easily identify and eliminate extraneous course material. For example, a course may have 30-45 CLOs. Collectively, these CLOs should exercise all levels of Bloom's Taxonomy. The distribution of CLOs for a typical course on the Bloom's taxonomy scale (cognitive domain) might be as follows:

- 10-20% are written at level 1-knoweledge (eg define the aerodynamic centre of an airfoil). Students can master these CLOs on their own simply by reading the textbook or with a minimum amount of direct instruction;
- 10-20% are written at level 2-comprehension (eg explain aerodynamic lift using first principles). Students can master these on their own with a minimum amount of direct instruction or in small group discussions;
- 50-60% are written at level 3-application (eg calculate aerodynamic forces on bodies by integrating surface pressure and shear stress distributions). This category usually represents the bulk of the CLOs in most engineering courses. It involves the application of mathematics, science and engineering principles to solve well-defined problems

Table 5: Examples of CLOs from AE162 – Aerodynamics (NB only three selected CLOs are shown here; the complete list can be found in ref. [11]). The right-hand column shows the POs addressed by each CLO [11].

Course Learning Objectives	PO
27. Design and perform (Outcome 3d is met as students work in teams of 3-4 to design and perform their experiment, as well as to write their lab report) an experiment to study the performance of an airfoil, analyse and interpret the results from this experiment, compare with analytical/computational predictions and other published experimental data (Outcome 3i is met as students research the literature for published data), and explain any discrepancies (Outcome 3g is met as students submit a full lab report for each experiment).	3b 3d 3g 3i 3k
36. Use the method of images to discuss and calculate aerodynamic interference for: - Wings flying in the vicinity of each other (ie wing/tail/canard combinations, biplanes, formation flying, etc); - Wind-tunnel boundaries; - Ground effects.	3a 3e
44. List several examples of regional, national and/or global contemporary problems related to aerodynamics (eg environmental issues, natural resources and energy conservation, etc), articulate a problem/position statement for each and explain what makes these issues particularly relevant to the present time.	3d 3g 3h 3i 3j

(exercises). Students may get a first exposure to the solution of these problems by reading textbook examples. However, in most cases, it is necessary for them to see a step-by-step solution demonstrated by the course instructor, followed perhaps by problem solving in small groups while being coached [12]. Lastly, a variety of homework problems, undertaken individually, will help solidify their problem-solving skills. A large percentage of the time in most engineering courses is spent helping students master level 3 skills;

- 10% are written at level 4-analysis (eg solve open-ended problems), 5-synthesis (eg design an airfoil to meet certain requirements), or 6-evaluation (eg define a set of figures-of-merit and use it to compare airplanes with similar mission requirements). CLOs at levels 5 and 6 are found usually in design courses and it is not necessary to include them in every engineering course. On the other hand, it is essential to include some CLOs at level 4 in every course, as they represent the minimum level of skill required if a student is to have working knowledge of the material. Needless to say, the instructor and students must spend a considerable amount of time in class, as well as outside of class, for students to become proficient in level 4 skills or above.

Two common mistakes in many engineering courses are as follows:

- Spending a great deal of time in class addressing level 1 and 2 CLOs;
- Covering too many topics or otherwise a large amount of material.

As a result of these two mistakes, there is usually not enough time to teach students important level 4 skills. While content is important, it is not useful unless it serves as the vehicle to help students acquire important problem solving and design skills. Content taught at levels 1 and 2 or even 3 is of little practical value in the real world of engineering.

CLOs also offer an effective way to communicate course expectations to students and give a clear picture of what they should be able to do, if they pass the course. This is important for instructors of follow up courses as well as for new instructors who may be teaching the course for the first time.

Course Learning Activities

With a set of specific, detailed and measurable CLOs in hand, the course coordinator may proceed to design lectures, in-class activities, assignments, projects and experiments that teach the skills described in each CLO and offer students opportunities to practice these skills. Some of the new assignments, introduced in several courses for the purpose of addressing specific POs, are shown in Table 6.

Table 6: Assignments designed to address critical areas of the POs.

Course Assignment	Courses in which Assignment was Introduced	PO
Students design the experiments they perform in various laboratories [13].	ME113-Thermodynamics ME114-Heat Transfer ME120-Experimental Methods AE162-Aerodynamics AE164-Compressible Flow	3b
Students discuss the economic, environmental, social, political, ethical, safety, liability and manufacturability constraints of their aircraft/spacecraft design.	AE170A&B-Aircraft/ Spacecreft Design	3c
Students are taught team skills and required to assess formally the performance of their teammates using specific criteria.	ME120-Experimental Methods AE162-Aerodynamics AE164-Compressible Flow AE170A&B-Aircraft/ Spacecreft Design ME195A&B-Senior Design Project	3d
Students identify, formulate and solve open-ended problems [14]. Some of these problems involve the integration of materials from two or more courses [15].	ME111–Fluid Mechanics ME113-Thermodynamics ME114-Heat Transfer AE162-Aerodynamics AE164-Compressible Flow AE165–Flight Mechanics AE167-Aerospace Propulsion	3a 3e
Students research, present and discuss in-class safety, ethics and liability issues in AE.	AE170A&B-Aircraft/ Spacecreft Design	3f 3h
Students research, present, and discuss in-class contemporary engineering applications and their impact in a global and societal context [16].	ME111–Fluid Mechanics ME113-Thermodynamics ME114-Heat Transfer AE162-Aerodynamics AE164-Compressible Flow AE165-Flight Mechanics AE167-Aerospace Propulsion	3h 3j

COURSE ASSESSMENT

Figure 2 shows the process of course assessment. When performance targets are not met for a particular outcome in a course, outcome champions, course coordinators and instructors discuss and implement improvements and the course is re-assessed until the targets are met. If course performance targets are met for an outcome, then the course is re-assessed after three years. If a course addresses more than one of the outcomes, as is usually the case, the same course may be re-assessed for a different outcome in the following terms. An example of course assessment for a specific outcome is shown below.

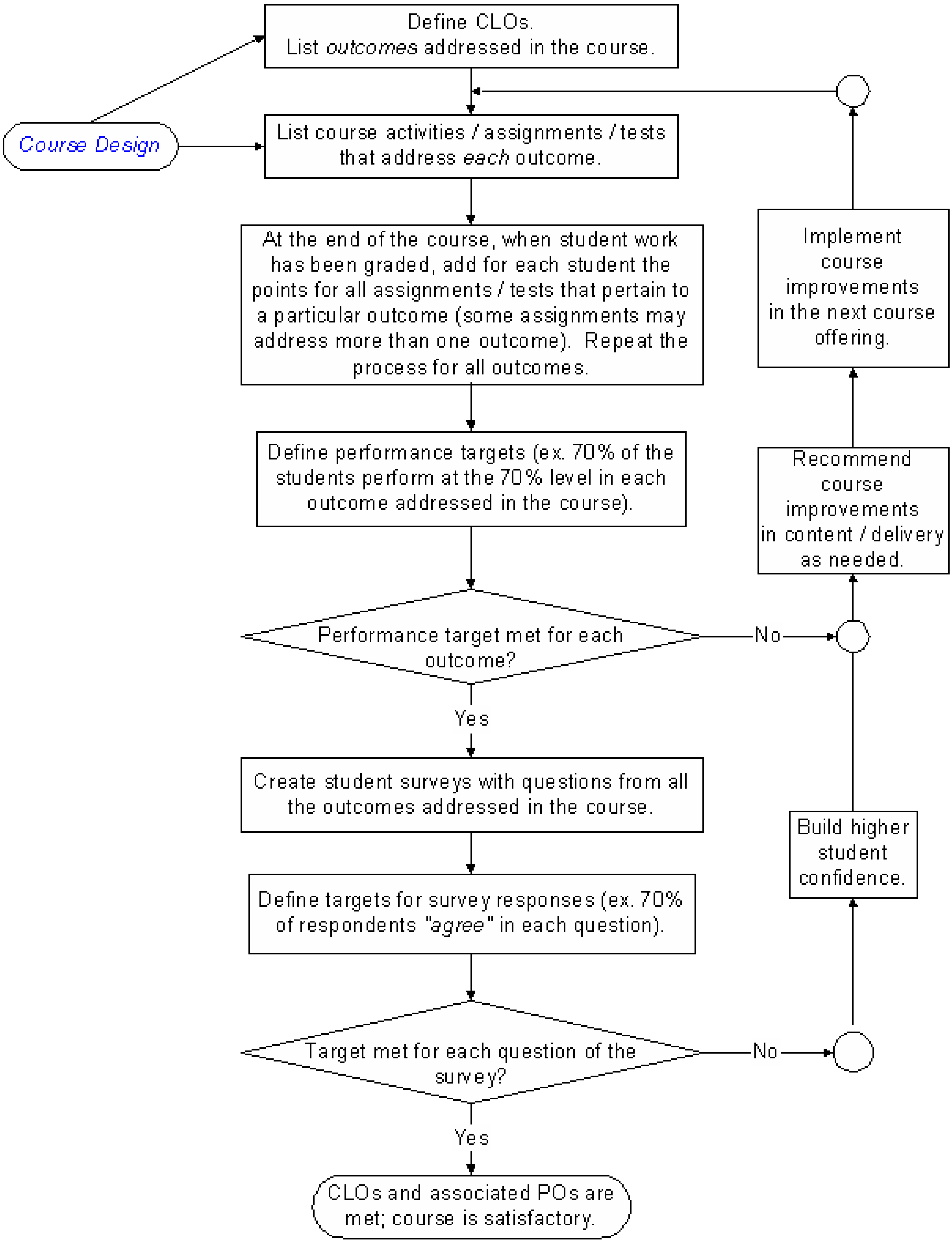

Figure 2: Course assessment flowchart.

AE170A&B – Aircraft Design: Fall 2002-Spring 2003 Assessment of Outcome 3c

Firstly, it should be noted that AE170A&B addresses six outcomes (see Table 2); only the assessment of Outcome 3c is presented here.

Course activities related to outcome 3c: Students undertake the following:

- Discuss airplane design in class during lectures;
- Design airplanes and write 12 detailed design reports;
- Give four design briefings in the course of the year;
- Respond in writing, individually to over 100 design questions;
- Participate in the SAE Aero-Design West Competition, which involves the design, manufacture and flight testing of a remotely-controlled, heavy-lift, cargo airplane. In this competition, they make an oral presentation to a panel of experts from industry and they are graded on their report, drawings, their ability to predict their payload, as well as on the performance of their airplane.

Course Assessment Summary: AE170A&B met the performance targets for Outcome 3c.

Student Performance Summary: Student performance exceeded the targets. In AE170A, 71% of the students performed at 85% or higher, while in AE170B, 83% of the students performed at 85% or higher. All students performed at 60% or higher in both courses. In general, students followed the design process fairly well and were creative in providing solutions to any problems they encountered.

Student Survey Results: In general, student responses showed a high level of confidence in design skills, with attribute (3c-11) being the only exception (see Table 7). It should be noted that some of the attributes listed on the survey are emphasised more in AE170A, while others in AE170B. This explains the different levels of agreement in the two parts of the course, for some of the attributes.

Recommendations for Course Improvements: After the first flight tests in AE170B, a class meeting should be devoted to discuss the following:

- Possible reasons for deviation between predicted and measured performance of their airplanes;
- How much difference between predicted and measured performance can be attributed to each factor.

Table 7: AE170A&B students' survey results.

This course has increased my ability to:	Agree	Not Sure	Disagree
3c-1 Develop a flowchart of the design process.	29% (67%)	(17%)	71% (17%)
3c-2 Define *real world* problems in practical (engineering) terms.	71% (100%)	29%	
3c-3 Investigate and evaluate prior or related solutions for a need I am trying to address.	86% (67%)	14% (17%)	(17%)
3c-4 Develop constraints and criteria for evaluation.	86% (83%)	14% (17%)	
3c-5 Develop and analyse alternative solutions.	57% (83%)	29%	14% (17%)
3c-6 Choose the *best solution* considering the trade-offs between the various solutions.	86% (83%)		14% (17%)
3c-7 Develop final performance specifications.	100% (67%)	(33%)	
3c-8 Communicate the results of my design orally as well as in writing (sell the design).	86% (100%)		14%
3c-9 Build a prototype and demonstrate that it meets performance specifications.	NA (67%)	NA	NA (33%)
3c-10 List and discuss several possible reasons for deviations between predicted and measured design performance.	71% (83%)		29% (17%)
3c-11 Choose the most likely reason for deviation between predicted and measured design performance and justify the choice.	57% (50%)	14% (50%)	29%

Note: Numbers without parentheses are the survey results from AE170A, while the numbers in parentheses are the results from AE170B.

CONTINUOUS IMPROVEMENT

The most critical part of the process is closing the loop in Figures 1 and 2 by implementing the course and curriculum improvements recommended by course coordinators and outcome champions.

Figure 1 involves design and assessment of the entire curriculum and hence requires input from all programme faculty. Identifying the courses in which a particular outcome is addressed (step 4 in Figure 1) is not always obvious, at least for some of the outcomes. In the ME programme at the SJSU, outcomes 3d and 3f presented such a challenge. Teamwork and engineering ethics were addressed only in the *Introduction to Engineering* course (E10). However, as was mentioned earlier, all the outcomes must be addressed and assessed in at least one upper division course since many engineering students transfer to the SJSU from community colleges.

The ME *Senior Design Project* course had to be redesigned for this purpose, from a loosely coordinated independent study course to a more structured course that addresses both of these outcomes through a series of guest speakers, follow up assignments and assessment of student performance in these assignments. Closing the loop in Figure 1 is not always straightforward. For example, poor student performance in outcome 3a, documented in several upper division courses, may be an indication that students lack the prerequisite skills in mathematics and science. The improvements, in this case, may have to be implemented in courses outside the department.

Figure 2 shows two kinds of course improvements that may be necessary in any given course. The first kind (lower loop) assumes that student performance meets the targets, while survey responses do not. In order to remedy the situation, course instructors simply need to build their students' confidence by making them more aware that they are developing the skills outlined in each of the survey questions. The second kind (upper loop) assumes that student performance does not meet the targets. Whether survey responses meet the target or not is irrelevant in this case. Changes are required in one or more of the following:

- The course content and associated CLOs;
- The course learning activities and the way these activities are administered;
- The way that the CLOs and associated POs are assessed in the course. For example, if students consistently score low on a given outcome, the course instructor may have to spend more time in class addressing the skills related to this outcome and assign additional homework.

In some cases, some course material may have to be omitted from the course, so that more time is dedicated to more fundamental topics and skills. Re-assessment will be necessary to confirm that any changes implemented have produced the desired results.

SUSTAINABILITY OF THE PROCESS

To make a programme assessment process sustainable, the workload must be distributed over time, as well as among as many of the faculty members as possible. Given that most, if not all, of the work in assessing outcomes is in course assessment, it is critical that the assessment workload of course coordinators is minimised. The timeline proposed in Table 4 distributes the workload over a period of six years and requires assessment of only two outcomes per semester. Assuming that faculty are familiar with and willing participants in the process, an outcome may be assessed and summarised in any given course in approximately one hour (see example course assessment presented earlier). Naturally, this estimated time needs to be multiplied by the number of outcomes addressed in the course. On the other hand, not all the outcomes in a given course need to be assessed in the same semester.

In summary, in order to minimise the faculty workload related to assessment in a given programme, the following needs to be undertaken:

- The workload must be distributed among as many faculty members (course coordinators) as possible;
- The programme assessment should involve as many courses as possible;
- Each course should be coordinated by a different faculty member;
- Each course should be assessed for the lowest possible number of outcomes.

CONCLUSION

In this article, the author describes the design and implementation of a systematic process to define, address and assess programme outcomes. The AE and ME programmes at San José State University used this process from 2002 through 2005 in preparation of the fall 2005 ABET visit. Evaluators found this approach most comprehensive and expressed their satisfaction that it is indeed used to improve both programmes.

A number of significant challenges that can be anticipated in sustaining such a process are as follows:

- Convincing faculty of the value of assessment, as the idea of continuous assessment is fairly new to higher education;
- Structuring the process without undue increase in workload;
- The evaluation criteria for faculty in most engineering schools emphasise research productivity rather than teaching. Course development, assessment and programme improvement do not carry nearly as much weight in the retention, tenure and promotion process [17];
- Lack of communication about teaching, learning and course content [18].

To promote continuous programme improvement, a paradigm shift in faculty culture is needed. The evaluation criteria for faculty should give equal emphasis on course/laboratory development and quality teaching, and recognise that assessment is an integral part of both. In addition, institutions need to promote the exchange of ideas among faculty regarding teaching, learning and assessment practices. Robert Hochstein explains as follows:

> *Ultimately, quality in the undergraduate experience is defined by quality in teaching. The reward system in higher education simply must recognize professors who are effective in the classroom, who spend time with students, and who engage their colleagues in talk about teaching. Without such a commitment, fine words about strengthening undergraduate education will be simply a diversion* [19].

This paradigm shift over time will lead more faculty to:

- Reflect on what works well and what needs to be improved in their courses;
- Communicate more with their colleagues about teaching practices, student learning and expectations for course content;
- Utilise feedback from all sources to modify their courses, so that they can maximise student performance in critical areas.

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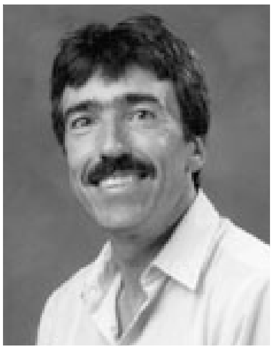
BIOGRAPHY



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